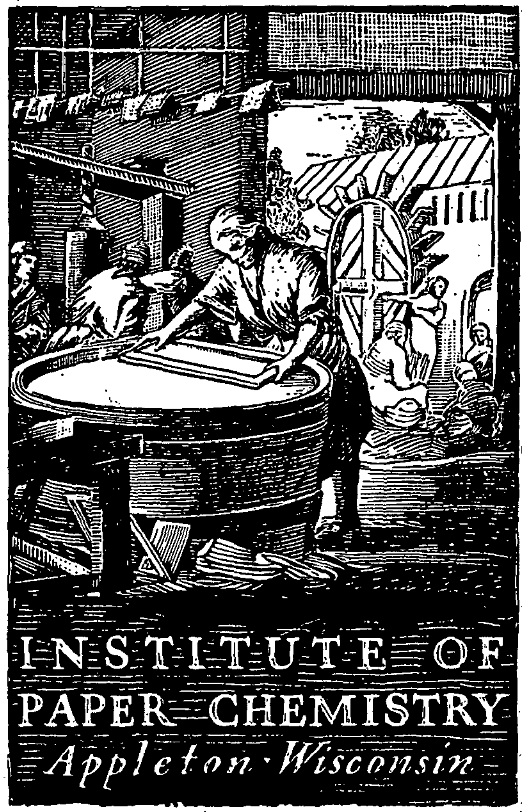

PRELIMINARY MATHEMATICAL MODEL OF A VACUUM DRUM WASHER

Project 2893

Report One

A Progress Report

to

MEMBERS OF GROUP PROJECT 2893

December 4, 1970

MEMBERS OF GROUP PROJECT 2893

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Container Corporation of America

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

PRELIMINARY MATHEMATICAL MODEL OF A VACUUM DRUM WASHER

SUMMARY

A mathematical description of a vacuum drum washer as used in kraft brown stock washing has been developed. The equations describe the dynamic fiber, water and dissolved solids balances in the washer. This complex system of equations is solved using simple finite differences to yield numerous state variables such as basis weight, consistency solids content of discharge pad, volume and solids content of filtrate, vat level, etc. Input parameters are pulp characteristics such as specific surface, specific volume, and compressibility coefficients, and stock flow rate, consistency, and dissolved solids.

At present the model suffers from what appears to be an inadequate solids balance in the wash section of the vacuum drum washer. The basis weight, consistency, and drum speed from the model under conditions equivalent to a real washer at Consolidated's mill at Wisconsin Rapids, Wis., were considerably different but are thought to be due to the description of the pulp characteristics.

A listing of the computer program of the model is presented in the Appendix.

INTRODUCTION

The vacuum drum washer is one of the many components which make up the kraft recovery cycle. It has been said as a matter of common knowledge that the washing process is a critical stage of pulping from an economic point of view. Too much wash water results in higher costs in the kraft recovery cycle due to a higher evaporation load. Too little wash results in a dirty pulp and loss of chemicals. The loss of chemicals is found not only in the black liquor carry-over, but also in consumption of bleaching chemicals further down the pulping process.

In the pulping industry there are basically two types of pulp washing configurations. The most predominant one is multistaged, multiple unit vacuum drum washing. This is usually employed where batch digesters comprise the means for the pulping operation. Where continuous pulping operations are used, and especially with the Kamyr digester, a one-stage vacuum washing is preceded by diffusion washing within the digester itself. This latter configuration is employed at Consolidated Papers, Inc., and forms the basis for this study.

This report will be concerned only with the vacuum drum washer, since it is the most predominant unit operation in the industry. Upon its completion, the diffusion washing operation will then be studied.

The purpose of this portion of Project 2893 is to provide a mathematical model of the washing process for simulation purposes. The model will have several objectives: 1) steady state operation for design and optimization purposes, and 2) dynamic operation for process control purposes.

The model basically is built upon material and energy balances for the three fundamental components of pulp stock: 1) water, 2) fiber, and 3) dissolved solids or solute. Although the model is for the single brown stock washer, it can be easily modified to any number of vacuum drum washers.

THEORETICAL DESCRIPTION OF A VACUUM DRUM WASHER

Although there are several styles and designs of vacuum drum washers, it is necessary here to describe a general conceptual picture of the washer for modeling purposes. When the model is applied to a specific washer, it may be necessary to add or modify various characteristics of the particular washer in order to make it relevant to the proposed usage.

The vacuum drum washer operates on the basis of three fundamental processes or steps: 1) filtration or pad formation, 2) simultaneous, cocurrent permeation of liquid and air (henceforth referred to as "two-phase flow"), and 3) the actual washing step. As the drum dips into the vat of stock, the first mentioned process takes place: namely, pad formation. As the surface of the drum leaves the stock, the two-phase flow process begins. From this point on, the mass of the pad is fixed and only permeation through the pad takes place. At the first shower, the pad is resaturated with wash liquor (or water). This step is again followed by the two-phase flow process.

The mathematical model is constructed according to these three processes, by means of quantitative material and energy balances. The dynamics of the vat level and concentrations of fiber and solids are also included. It should be noted that this model will not predict or describe various operating problems such as poor pad formation, or foaming problems due to excessive wash liquor temperatures. Until these phenomena can be adequately described on a quantitative basis, they cannot be included in the model.

At this point we want to make some basic assumptions about the various processes.

1. The stock or slurry in the vat is composed of three components: a) water, b) fiber, and c) dissolved solids.

2. Complete retention of fibers on the drum surface is assumed.

3. Fiber properties such as specific surface area and specific volume are constant.

4. No interaction between pad and septum.

Let us now describe the filtration or pad formation process.

FILTRATION PROCESS

The filtration of fiber slurries has been well studied at The Institute of Paper Chemistry. A recent article by Meyer (1) summarizes these current procedures.

The driving force for the filtration process is the pressure difference, ΔP_T, between the inside of the drum and the outside. As will be discussed later, this pressure difference may vary according to the location of the drum surface.

As the drum enters the slurry, the resistance to fluid flow is due solely to the wire screen or septum. According to the Forchheimer relationship, the filtrate velocity, U_o, and the pressure drop ΔP_w are related for a unit area of the septum by

$$\Delta P_w = \mu a_w U_o + \rho b_w U_o^2 \qquad (1)$$

where μ is the fluid viscosity, ρ is the fluid density, a_w is the viscous resistance coefficient of the septum, and b_w is the inertial resistance coefficient of the septum. During this brief period of flow, a pad of fibers will begin to form, which results in additional resistance to flow such that

$$\Delta P_T = \mu(a_w + a_p)\, U_o + \rho(b_w + b_p)\, U_o^2 \qquad (2)$$

where a_p is the viscous resistance coefficient and b_p is the inertial resistance coefficient of the pad of fibers. Equation (2) is valid, provided there is no hydrodynamic interaction taking place between the septum and pad.

The resistance of the septum is constant; however, the resistance coefficients of the pad will change not only because of increasing pad thickness, but also because of the compressible nature of the fibrous pad. This compaction is due to the pressure drop across ΔP_p the pad proper.

$$\Delta P_p = \Delta P_T - \Delta P_w \qquad (3)$$

There are various methods for describing this compaction and the Campbell formula was chosen for this study

$$\rho_p = M(P_f)^N \qquad (4)$$

where ρ_p is the pad density and M and N are coefficients determined previously by experimental means for the particular pulp in question. Equation (4) thus describes a density distribution within the pad as a result of a compacting stress distribution P_f. Since we are not concerned with these distributions, we will employ only the pad averaged values.

$$\Delta P_p = \Delta P_f = \int_o^T P_f dT \qquad (5)$$

According to Ingmanson and Andrews (2) the average mat density becomes

$$\rho_p = (1-N/2)^2 \; M \; (\Delta P_p)^N \tag{6}$$

It should be noted that the pad density refers to the mass of ovendry (o.d.) fibers per unit volume of pad. From this pad density, one may estimate the average porosity $\bar{\varepsilon}$, (or void volume) of the pad through the use of the specific volume, $\underline{v}$, of the fiber.

$$\bar{\varepsilon} = 1 - v \cdot \rho_p \tag{7}$$

The specific volume of the fiber must be determined experimentally for each species and represents the water-swollen volume of the fiber.

The coefficient $\underline{a}_p$, $\underline{b}_p$ for the pad have evolved from the Kozeny-Carman equations and take the form

$$a_p = \alpha(1-\bar{\varepsilon})^2 \; S_v{}^2 T/\bar{\varepsilon}^3 \tag{8}$$

$$b_p = \beta(1-\bar{\varepsilon}) \; S_v T/\bar{\varepsilon}^3 \tag{9}$$

where α and β are coefficients, $\underline{S}_v$ is the specific surface of the fiber, and $\underline{T}$ is the pad thickness. The coefficient α is equivalent to the Kozeny factor, $\underline{k}$. The specific surface $\underline{S}_v$ is determined experimentally at the same time as the determination of the specific volume. Usually the specific volume, $\underline{S}_w$, on a mass basis is determined and the volume basis is calculated from

$$S_v = S_w/v \tag{10}.$$

The Davies-Ingmanson empirical formulas for the porosity dependency of the Kozeny factor have been employed and are

$$\alpha = k_1\bar{\varepsilon}^3[1+k_2(1-\bar{\varepsilon})^3]/(1-\bar{\varepsilon})^{1/2} \qquad \text{for } \bar{\varepsilon} \geq 0.7 \tag{11}.$$

$$\alpha = 5.60 \qquad \text{for } \bar{\varepsilon} < 0.7$$

Here, the constants are known; $k_1 = 3.5$ and $k_2 = 57.0$. Han and Ingmanson (3) express the coefficient β as

$$\beta = k_3\sqrt{\alpha} \qquad (12)$$

where $k_3 = 0.1$.

The buildup of the pad results from the filtration of the fibers in the slurry such that the incremental increase in pad weight, ΔW is related to the filtrate velocity, U_o, and the slurry consistency, C_v, in the vat by

$$\Delta W = U_o\ C_v\ \Delta t/(1-C_v) \qquad (13)$$

and the total pad weight W

$$W = \sum_{o}^{t} \Delta W \qquad (14)$$

The consistency of the slurry is expressed as mass of o.d. fibers per mass of slurry. One can then arrive at the pad thickness, T.

$$T = W/\rho_p \qquad (15).$$

Equations (1-3, 6-9, 11-15) are solved simultaneously by trial and error for a particular time, t, and incremental time, Δt. Thus, we are able to calculate the pad mass, porosity, density, and filtrate velocity for each unit area of the drum surface.

TWO-PHASE FLOW

As discussed earlier, the next process encountered on the vacuum drum washer is that of simultaneous, cocurrent flow of a liquid (water) and air through the partially saturated fiber pad. To begin, we must define some terms. First there are basically three types of water associated with the cellulose fiber system: 1) bound or intermolecular water, strongly absorbed into the cellulose structure of the fiber; 2) intrafiber water retained in the lumen and microscopic pores of the fiber; and 3) interfiber water which occupies the void volume of the fibrous pad. In discussing the permeation and filtration processes, it is this third type of water which is readily available for flow. The former types of water require diffusion and higher temperatures for their removal.

A good example of the first two types of water is as follows. Many of us have observed the hygroscopic properties of paper during a very humid, muggy day. A dry piece of paper, after a period of time in this environment becomes "soggy" and begins to curl. This moisture is becoming absorbed by the cellulose and absorbed into the microscopic pores of fibers. A rough approximation of the amount of Types 1 and 2 water can be calculated from the swollen specific volume, $\underline{v}$. For a value of $\underline{v}$ = 2.50 cm.^{3}/g. we can say that a fiber weighing 1 g. contains 1.886 g. of water. This is computed from the knowledge that the density of cellulose is 1.63 g./cm.^{3} (4) or has a specific volume of 0.614 cm.^{3}/g. Thus, we may say that the critical consistency is about 34.6%. In terms of moisture content based on the mass of a wet fiber this amounts to 65.3% moisture. Thus, any moisture above this value indicates free water. It is interesting that Robertson (5) has corroborated this critical moisture content from the determination of the strength of a fiber bed during drying.

The free water content is usually expressed as the saturation, σ, which is defined as the fraction of the void volume, $\bar{\varepsilon}$, containing free water.

Thus, we can calculate the consistency of the pad, from its definition, at any location. Considering a unit area, the mass of fibers is $\underline{W}$. The mass of the "slurry" will be the mass of fibers plus the water in the void volume of the pad plus the water in the fiber. Thus, the consistency of the pad, C_p, is given by

$$C_p = W/\{[\sigma\bar{\varepsilon}W/\rho_p + (v-0.614)\ W]\rho+W\} \qquad (16).$$

The number, 0.614, represents the specific volume of pure cellulose as calculated from the inverse of the density of cellulose.

According to Brownell and Katz (6) there is a residual saturation, σ_r, which represents the maximum pore space eliminated from flow by capillary forces. It also represents the equilibrium saturation for a given porous media at a given pressure drop. Based on data for flow through packed beds, they have derived an empirical function based on the Capillary Number, N_{Ca}, where

$$N_{Ca} = K\ \Delta P/(\gamma \cos \theta) \qquad (17).$$

Here, K is the permeability of the porous bed, γ is the surface tension, and θ is the contact angle. Then

$$\sigma_r = (N_{Ca})^{-0.264}/86.3 \qquad (18).$$

Since K represents the inverse of the viscous resistance coefficient for Darcy flow, we may approximate K with an inverse of Equation (8) so that

$$K \approx \bar{\varepsilon}^3/[\alpha(1-\bar{\varepsilon})^2 S_v{}^2 T] \qquad (19).$$

The interfacial tension, γ, for the cellulose-water system should have a value of about 35 dynes/cm. (7), and a contact angle of about 10 deg. It should be noted, however, that the surface energy could change by an order of magnitude as a result of the dissolved solids and other surfactants in the black liquor.

The agreement of Brownell and Katz's work with that of Parker (8, 9) is rather crude. Parker's data are applicable for only one porosity ($\bar{\varepsilon}$ = 0.943) and, therefore, have limited use. Brownell and Katz, however, have a function which is porosity dependent even though the function may be inaccurate.

According to Brownell and Katz, the effective saturation, $\sigma_{\underline{E}}$, active in flow is determined by

$$\sigma_E = (\sigma - \sigma_r)/(1-2\sigma_r + \sigma\,\sigma_r) \qquad (20).$$

In discussing the permeation of a partially saturated porous bed, Sweeney (<u>10</u>) has assumed that each phase is continuous throughout the bed and that the total pressure drop through each phase is identical. His result is

$$\Delta P \cdot \sigma^3 = \mu aTU + \rho bTU^2 \qquad (21).$$

The factor of σ^3 results from the concept that σ represents the effective liquid phase fraction of the void volume for use in computing the pore velocity. The question of whether or not this approach is valid has yet to be determined. Sweeney has found good agreement for down flow packed beds.

It is this author's opinion that the effective saturation, $\sigma_{\underline{E}}$, from Brownell and Katz should be used in Sweeney's modified Forchheimer equation (21), since this saturation value will yield the active fluid available for flow. A treatment similar to the above has been attributed to Rapoport and Leas and is described by Scheidegger (<u>11</u>). They employed a different definition for the effective saturation $\sigma_{\underline{E}}$

$$\sigma_E = (\sigma-\sigma_r)/(1-\sigma_r) \qquad (22)$$

and suggested the use of an effective specific surface. The definition of this effective specific surface was not straightforward and they could only specify theoretical maximum and minimums from a knowledge of the capillary pressure distribution curves for the particular porous medium.

This completes the analysis of the fluid flow aspects of the vacuum drum washer. The next step or process for discussion is that of washing or reusing of the pulp.

PULP WASHING

Pulp washing, like that of two-phase flow in pulps, is a process in which there is very little information concerning the mechanism of the process. Sherman (12) and Pellet (13) have studied the process of washing for beds of synthetic fibers. In both cases the bed was fully saturated before the wash water was introduced. They each considered the case where the saturated bed was initially contaminated with a soluble material and then a modified step input concentration of wash water was applied. Sherman's work considered the equilibrium case where the rate of solute exchange between the fiber and the fluid follows a linear adsorption isotherm. Pellet continued on to study the case of intrafiber diffusion where the rate of solute exchange becomes much more complex.

The primary mode of solute removal in both of the studies is one of displacement of the interfiber fluid. There are varying degrees of deviation from the ideal displacement curve as a result of longitudinal dispersion or intrafiber diffusion. The situation with a pulp washer, however, is that the pad of fibers is dewatered as much as possible before the wash liquor is applied. Thus, the pad is not saturated and the mechanism of displacement is not available. Also, in many cases, the wash liquor is not at a fixed concentration, but may vary somewhat as a result of another washer downstream. The filtrate from this latter washer provides the wash liquor for the washer in question.

A less elegant treatment is that of Kuo (14). His description of filter cake washing considers the residual saturation liquid as a film, coating the "walls of a pore channel." While the wash liquor passes through this pore channel, the solute or dissolved solids diffuses from the residual liquid film to the wash liquor. As a result, he can express the solids concentration in the residual liquid film and in the exiting wash liquor as a function of time and initial concentrations.

At first this approach would not appear to be realistic; however, some thought should be given to its usefulness in this study. Considering the nature of the cellulose-water system, it is quite conceivable that such a film adheres to the fiber. This rather crude approach may account for the solute which has absorbed into the cellulose fiber as well as the solute in the residual liquid phase.

Another study worthy of mention, is that of Han and Bixler (15). They treated a packed bed of granular solids, which had reached a residual saturation equilibrium, as if it consisted of straight pore channels with blind side channels or pores. These side channels would retain the residual liquid after draining of the bed by some mechanical means. The dissolved solids in these pores would diffuse out toward the wash liquor flowing through the main channels. The treatment is rather complex and would require some prior experimental program for arriving at values of certain unusual parameters.

After considering the above models, it was concluded that they were not applicable. This is due to the fact that the duration of shower wash is much shorter than other washing processes. A crude estimate places the shower time on the order of ten seconds or less. Thus, a simple complete mixing model was employed for this study.

VAT DYNAMICS

The final element to be considered is that of the vat itself. Although the material balances for water fiber and solids are equivalent to a simple tank, a complication arises due to the geometry of the system. Referring to Fig. 1, a set of equations is given relating the vat level, L, and the cross-sectional area of the vat. The cross-sectional area of the vat without the drum is

$$A_v = \pi D_v^2/8 - L(D_v^2/4 - L^2)^{1/2} - (D_v^2/4) \times \tan^{-1}[L/(D_v^2 - L^2)^{1/2}] \tag{23}$$

while the cross-sectional area of the drum is

$$A_D = \pi D_D^2/8 - L\ (D_D^2/4 - L^2)^{1/2} - (D_D^2/4)\ \tan^{-1}[L/(D_D^2 - L^2)^{1/2}] \tag{24}.$$

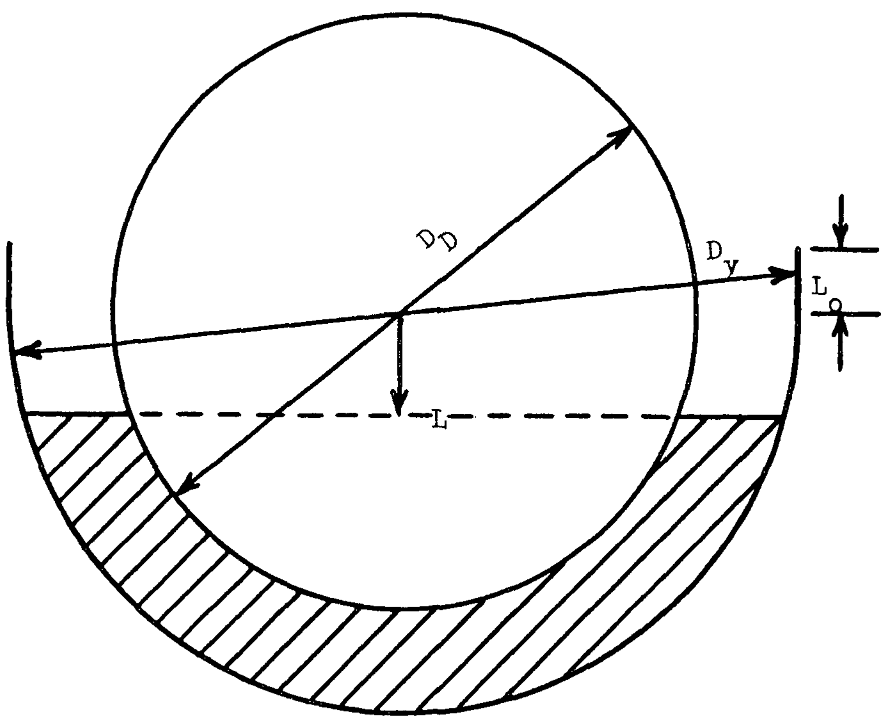

Figure 1. Cross Section of Washer Vat (Cross-Hatched Area Represents Stock)

The resulting cross-sectional area occupied by the stock is then the difference in areas (cross-hatched area in Fig. 1)

$$A_s = A_v - A_d \qquad (25).$$

The volume, of course, is the product of the area and width of the vat.

The volume of stock is determined by the material balance around the vat. The level is then determined through the inverse of Equations (23)-(25).

COMPUTER MODEL OF VACUUM DRUM WASHER

From a programming standpoint, there are four subroutines and one mainline program. They are interrelated according to Fig. 2.

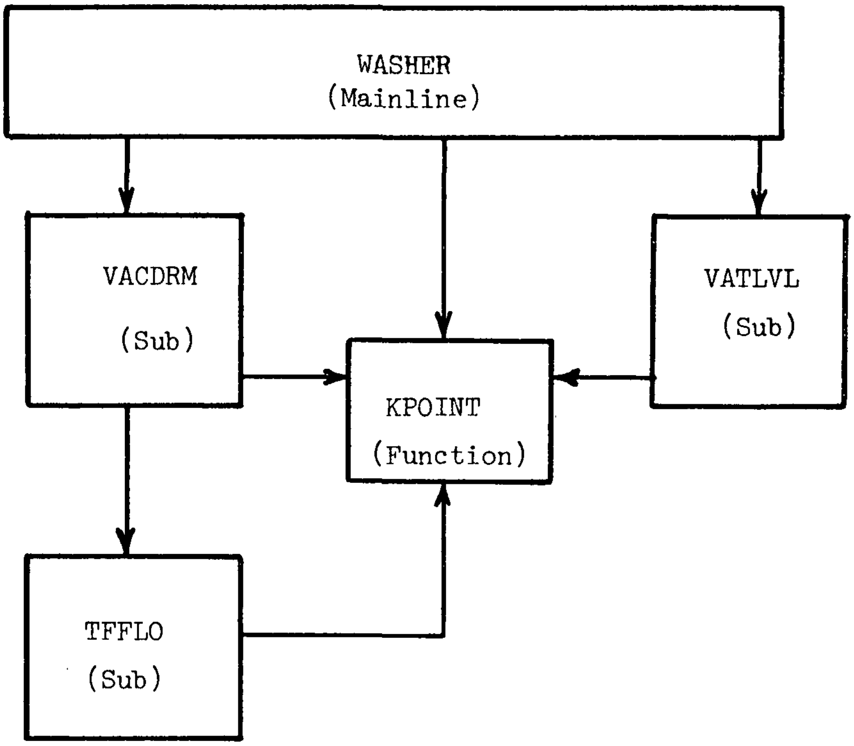

Figure 2. Block Diagram of Computer Program and Subroutines

Briefly, the mainline program (WASHER) performs necessary initialization of variables and parameters, performs material balances around the vat, incorporates the level feedback to the drum speed, and provides printout of numerous variables. The subroutine VACDRM computes pad formation, permeation velocities, and various other flows. The subroutine TFFLO computes the two-phase flow through the pad after formation and includes the shower wash section. The subroutine VATLVL computes the level in the vat from the inverse of Equations (23)-(25) through an iterative procedure. It is called the mainline program. A function subprogram (KPOINT) is used to compute the index for some storage locations of memory variables.

To give one a picture of the concepts of the model, an information flow diagram is shown in Fig. 3.

For a particular time, t, the volume and, hence, the level in the vat (LVLVAT) is computed from a material balance around the vat, i.e.,

$$\text{QSTOCK} + \text{VOLVAT}^{(t-\Delta t)} - \text{QPADI} - \text{QFIL} = \text{VOLVAT}^{t}.$$

The level in the vat is determined from VOLVAT. Similarly, that for the fiber and solids is:

$$\text{FBRIN} + \text{FBRVAT}^{(t-\Delta t)} - \text{FBROUT} = \text{FBRVAT}^{(t)}$$

$$\text{SLDIN} + \text{SLDVAT}^{(t-\Delta t)} - \text{SLDIMD} - \text{SLDFIL} = \text{SLDVAT}^{(t)}.$$

The variables QPADI and SLDIMD represent the water and solids in the pad before the showers. FBROUT and QFIL are computed in VACDRM and represent the fiber on the drum and filtrate removed. The solids computation are performed in TFFLO, where SLDFIL represents the solids in the filtrate. The consistency, CHSVAT, and solids concentration SLCVAT are computed in the mainline program.

Water and solids balances are also carried out around the shower section in TFFLO. From these computations the water in the exit pad, QPAD, and the solids, SLDPAD are determined.

The computer model is based on the equations and relationships present in the first portion of this report. Superimposed on these functions are various logical functions which describe certain operations and boundary conditions. The model will be composed of functional subroutines which facilitate the construction and later modifications.

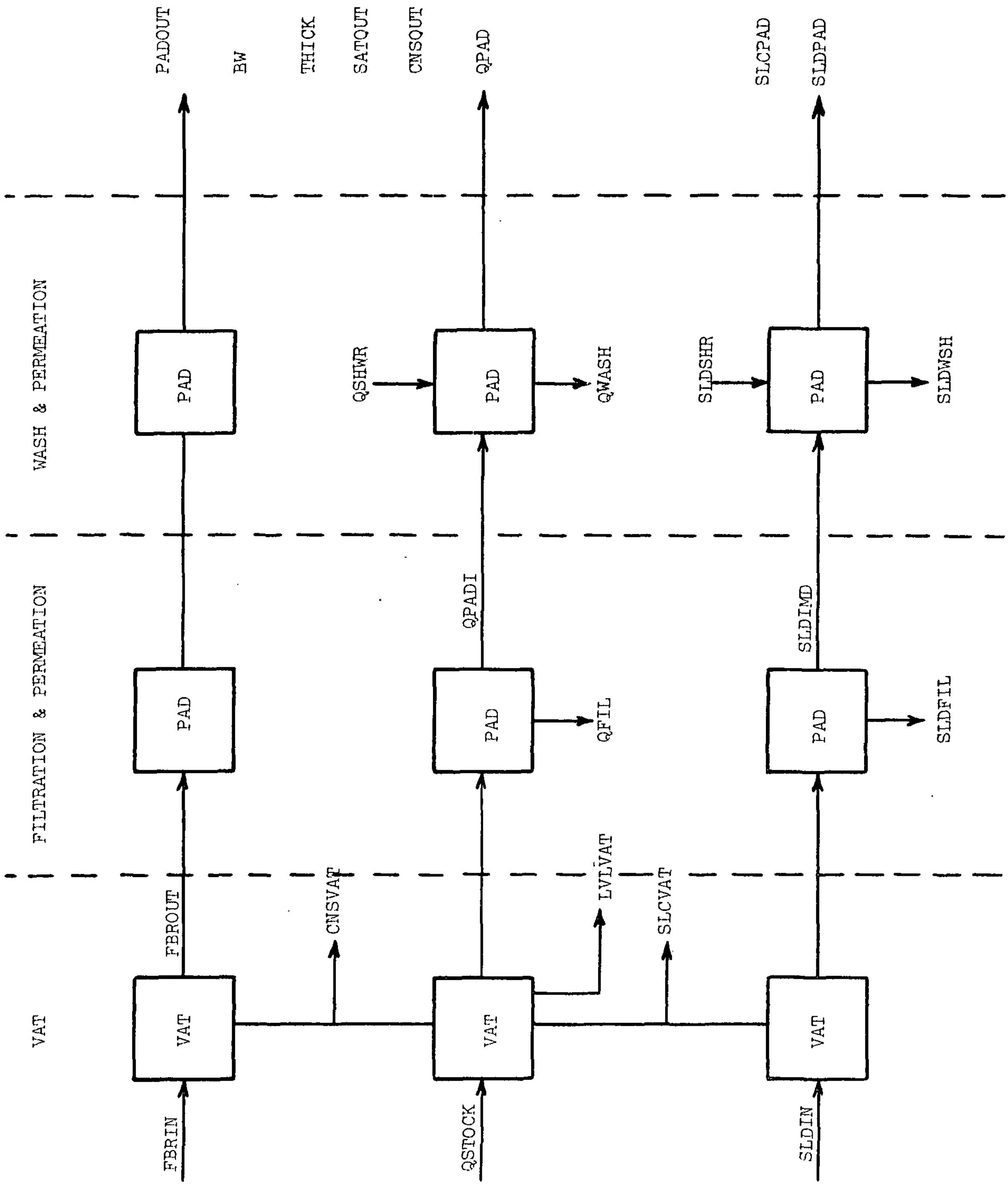

Figure 3. Logic Diagram of Fiber, Water, and Solids Balances

From a logical standpoint, the vacuum drum is divided into i logical sectors, such that its circumferential surface is divided into segments of length, δ. These logical sectors should not be confused with the physical sector found in many vacuum drum washes. The optimum value for i should be as low as possible without sacrificing accuracy in the solution of the equations. This value can be obtained through experience or trial runs.

The time increment, Δt, is then determined by the ratio of this sector length, δ, and the drum surface speed. Storage of most of the pad variables is maintained in a fixed location. A pointer in one of the subroutines (KPOINT) determines where the beginning point of the drum is located, and steps through on a "wrap-around" basis.

As the drum rotates, it passes through six logical switches. The first occurs at θ_I, the point where filtration begins at atmospheric pressure (see Fig. 4). The second is θ_P where filtration continues with the full drum vacuum. At θ_F the filtration process is terminated and two-phase flow begins. This latter process continues on to the point, θ_E, where the sheet is removed from the drum. In the interim, shower water is introduced at θ_{SB} and continues to θ_{SE}. Depending upon the saturation of the pad during this wash stage, either two-phase flow or ordinary permeation will take place.

To begin with, the level in the vat is designated as $L(t)$, which is a function of time, and is measured in the positive y direction as shown in Fig. 4. The diameter of the drum is D_D and the drum speed is ω_D. The point on the drum at which filtration begins is denoted by θ_I, and is defined as

$$\theta_I = \mathrm{Tan}^{-1}\ (2\ \ L(t)/D) \qquad (26).$$

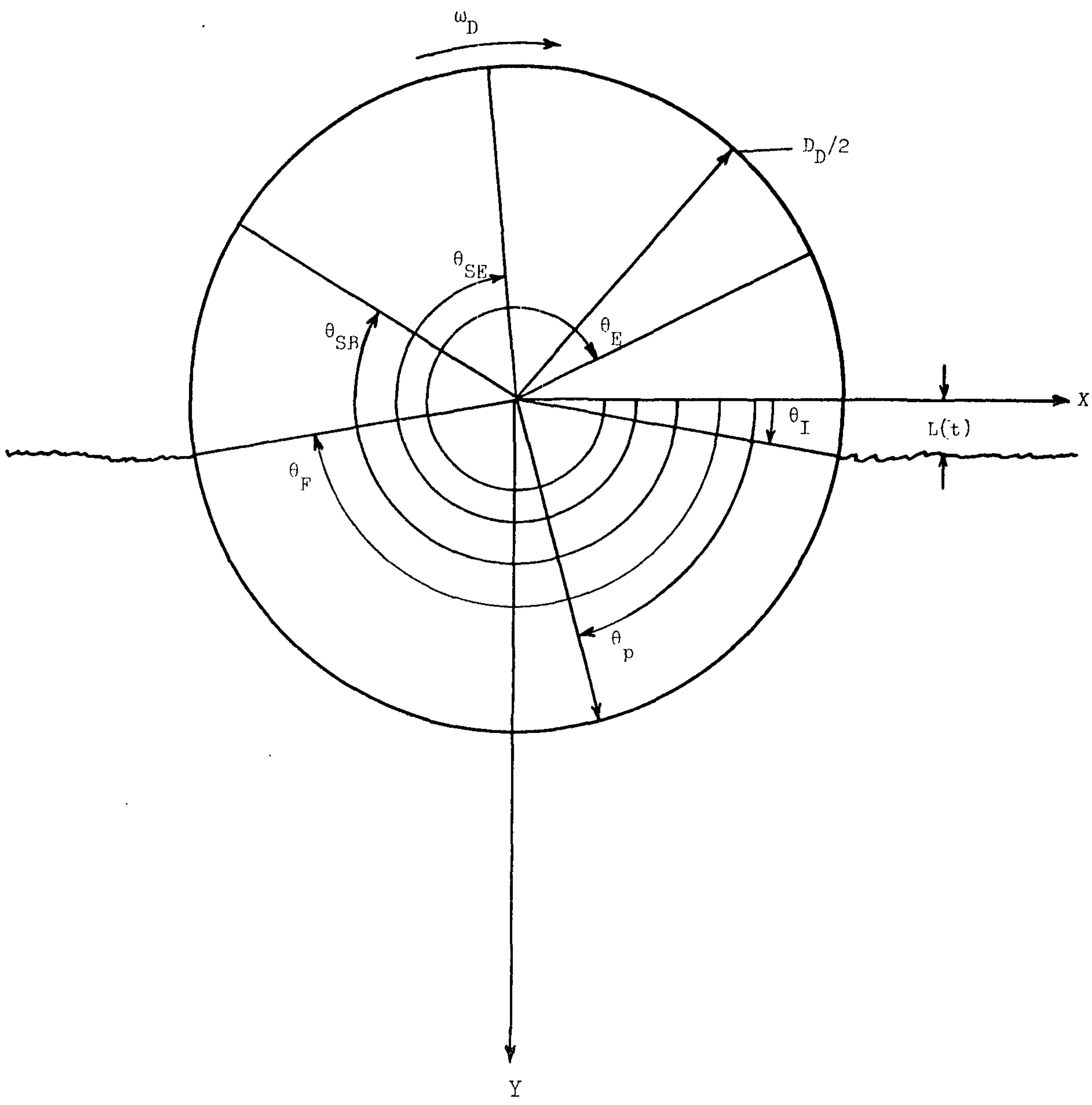

Figure 4. Diagram of Logical Switches for Boundary Conditions on Drum

Similarly, the angle at which filtration terminates and two-phase flow begins is denoted by θ_F where

$$\theta_F = 180 - \theta_I \qquad (27).$$

According to Keene (16) the pressure in the vacuum drum at the early stages of filtration is at atmospheric pressure. This is done in order to provide a fine filter pad on the drum surface. The driving force for the filtration will then be the difference in fluid head between the inside of the drum and the vat level. I have assumed this difference to be a constant 1 cm. of water. This initial filtration proceeds through an angle θ_p which has a value of about 75°. From this point on to θ_F, the vacuum in the drum is P_D. A problem arises in ascertaining an appropriate value for P_D. The usual vacuum measure on the drop leg outside the drum is about 8 inches Hg. Keene, however, believes that the effective vacuum at the drum surface is about 6 inches Hg. The transition from no vacuum to full vacuum is accomplished with a ramp function.

The pad formation equations, modeled in the subroutine (VACDRM), is the means for simultaneously solving the equations noted on page 7. The subroutine is entered with an initial value of the ΔP_p which is assumed equal to the total pressure drop $\Delta P_T = -P_D$. This value is used to compute the pad density $\bar{\rho}$ from Equation (6). The porosity, $\bar{\varepsilon}$, and α and β are computed from Equations (7, 11, 12). A temporary basis weight is determined from Equations (13, 14) and this value is used to determine the resistance coefficients a_p and b_p from Equations (8, 9, 15). The filtrate velocity is then computed from a rearrangement of Equation (2). If this velocity has changed by more than 1% from the previous velocity within the same logical sector, a new pad pressure drop is computed from Equations (1, 3). The abovementioned steps are repeated until the filtrate velocity converges, at which point the subroutine exits to the calling program.

The subroutine for the two-phase flow (TFFLO) process is called after completion of pad filtration. This subroutine first computes the capillary number, N_{Ca}, the residual saturation, the effective saturation, and the effective pressure drop, $\Delta P_T \sigma_E^3$ from Equations (18, 20, 21). If no shower is present, the filtrate velocity is computed from the rearranged Forchheimer Equation (2). The saturation is then computed from a fluid balance on a unit area of the sector, so that

$$\sigma(t+\Delta t) = [\sigma(t)\bar{\varepsilon}W/\bar{\rho} - U_o\Delta t]/(\bar{\varepsilon}W/\bar{\rho}) \qquad (28).$$

If $\sigma(t+\Delta t) \geq \sigma_r$ then the value is accepted, otherwise $\sigma(t+\Delta t) = \sigma_r$ and the filtrate velocity is adjusted accordingly.

If shower water is present, one must first compute a shower water velocity, U_s, entering the pad. This velocity is computed from the known volumetric flow rate of the showers and is assumed to be uniformly applied to the drum surface from θ_{SB} to θ_{SE}. A filtrate velocity also is computed. If $\sigma = 1$ the shower velocity cannot exceed the filtrate velocity and thus the difference becomes excess shower water. Otherwise the shower water velocity is accepted and the saturation is computed from a material balance similar to Equation (28). A solids balance is run on the pad by assuming complete mixing of shower water with the water in the pad.

At the end of the subroutine, all of the excess shower water is summed up. The beginning point for shower water application is decremented by one sector to increase the shower area. This is equivalent to the excess water running down the surface of the drum toward the vat. If there is no excess shower water, and if the beginning point for shower water had previously been shifted down, an attempt is made to return it to θ_{SB}. In this manner the starting point for shower or wash water is continually seeking its equilibrium value. At this place in the subroutine, control is returned to the calling program.

PRELIMINARY RESULTS

The model has been run many times, with each run requiring modifications to provide refining. It is with regret that the author was unable to complete the model in time for this report. The results available at the time of writing of this report are presented.

A one-day trip was made to Consolidated's Wisconsin Rapids pulp mill in order to obtain some operating data from the brown stock washer. A sample of the inlet stock was taken to the Institute so that analysis of the fiber properties could be determined. Since the sample size was not large enough, it was necessary to also use the airdry pad sample. Because of this problem, it is believed by the author, that the specific surface and compressibility coefficients may be in error. All of these results, however, are presented in Table I and were employed in the model as data.

TABLE I

DATA OBTAINED AT CONSOLIDATED PAPERS
JULY, 1970

(Kraft softwood)

Specific surface S_v		2975.0 cm.$^{-1}$
Specific volume v		3.09 cm.^{3}/g.
Compressibility coefficients		
	M	0.001345
	N	0.386
Stock temperature		82°C.
Wash temperature		67°C.

A piece of the washed pad from the discharge side of the washer was obtained and immediately weighed. An outline of the pad was then traced on a piece of paper so that its area could be determined. The pad was then air dried over a weekend and again weighed. These results are presented in Table II.

TABLE II

COMPARISON OF MODEL RESULTS WITH MILL DATA

	Sample Pad	Model
Area	218 $cm.^2$	--
Airdry weight	35.0 g.	--
Thickness	1-1/8 inches (2.9 cm.)	3.5 cm.
Consistency	13%	18%
Basis weight	1600 $g./M^2$	3840 $g./M^2$
Pad density	0.0555 $g./cm.^3$ [a]	0.1095 $g./cm.^3$

[a] Calculated from a.d. weight/(thickness x area).

The stock and wash water temperatures were also measured.

No dissolved solids data were obtained.

The model was run using dimensions on the washer as obtained from Consolidated. Values of stock inlet flow rate of 5370 g.p.m. at 1% consistency and 6% dissolved solids were estimated for actual washer conditions. At Consolidated the washer has a drum speed controlled by vat level. This controller has a proportional control of unity and reset of 0.25. The proportional control was incorporated in the model (the reset was left out) to provide some numerical stability in the solutions and arrive at steady state more quickly.

The model was allowed to run to steady state which required about 2 minutes simulation time (3 minutes computer time on IBM 360 Model 50). At this point, the state variables of the process were obtained and are plotted in Fig. 5 and 6. At this steady state condition the vat level was about two feet below the axis of the drum whose speed was about 1 r.p.m. Exit pad characteristics are given in Table II. The fiber and water balances all checked out; however, the solids balance showed problems in the shower zone.

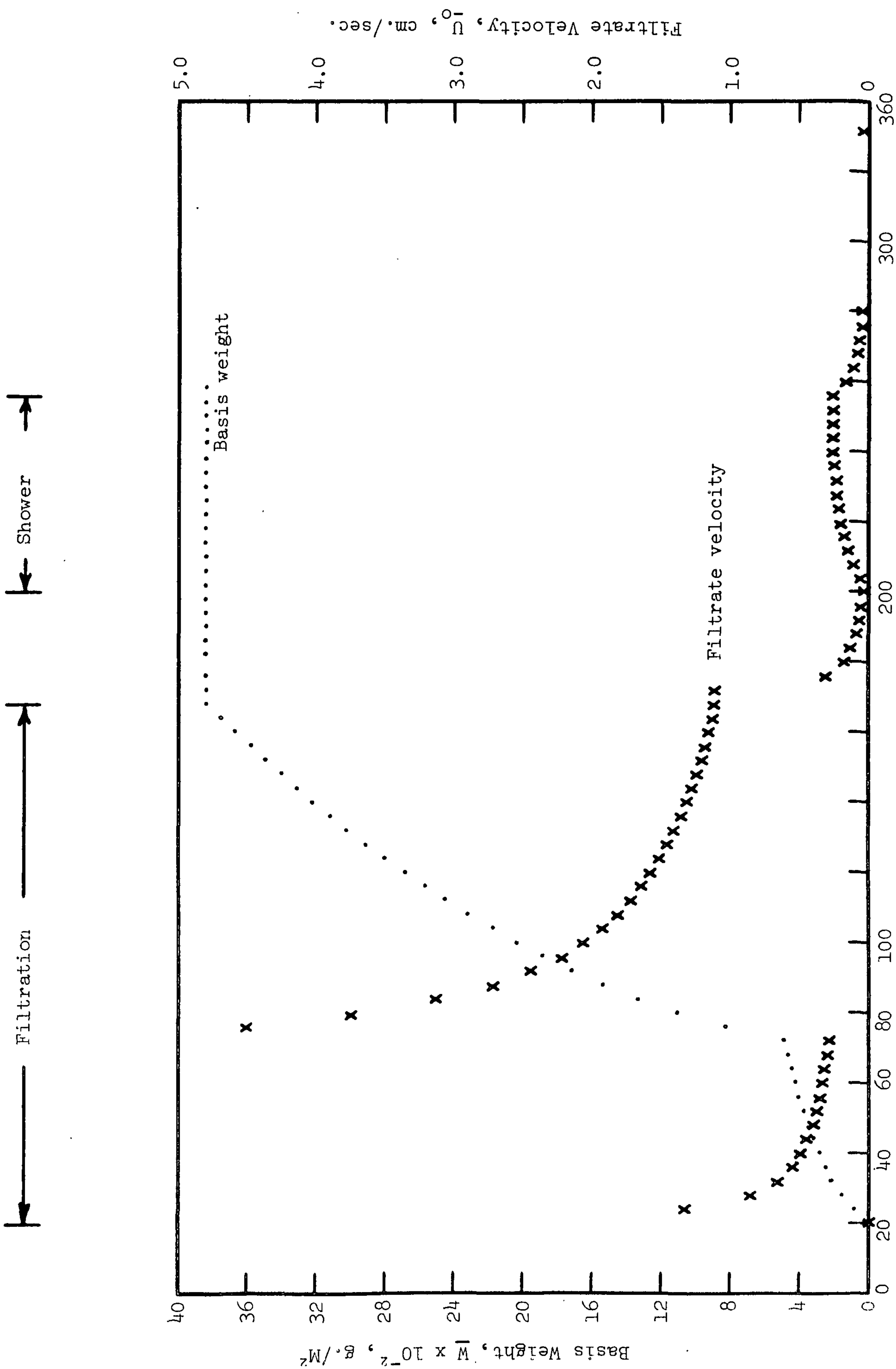

Figure 5. Basis Weight and Filtrate Velocity Along Contour of Drum

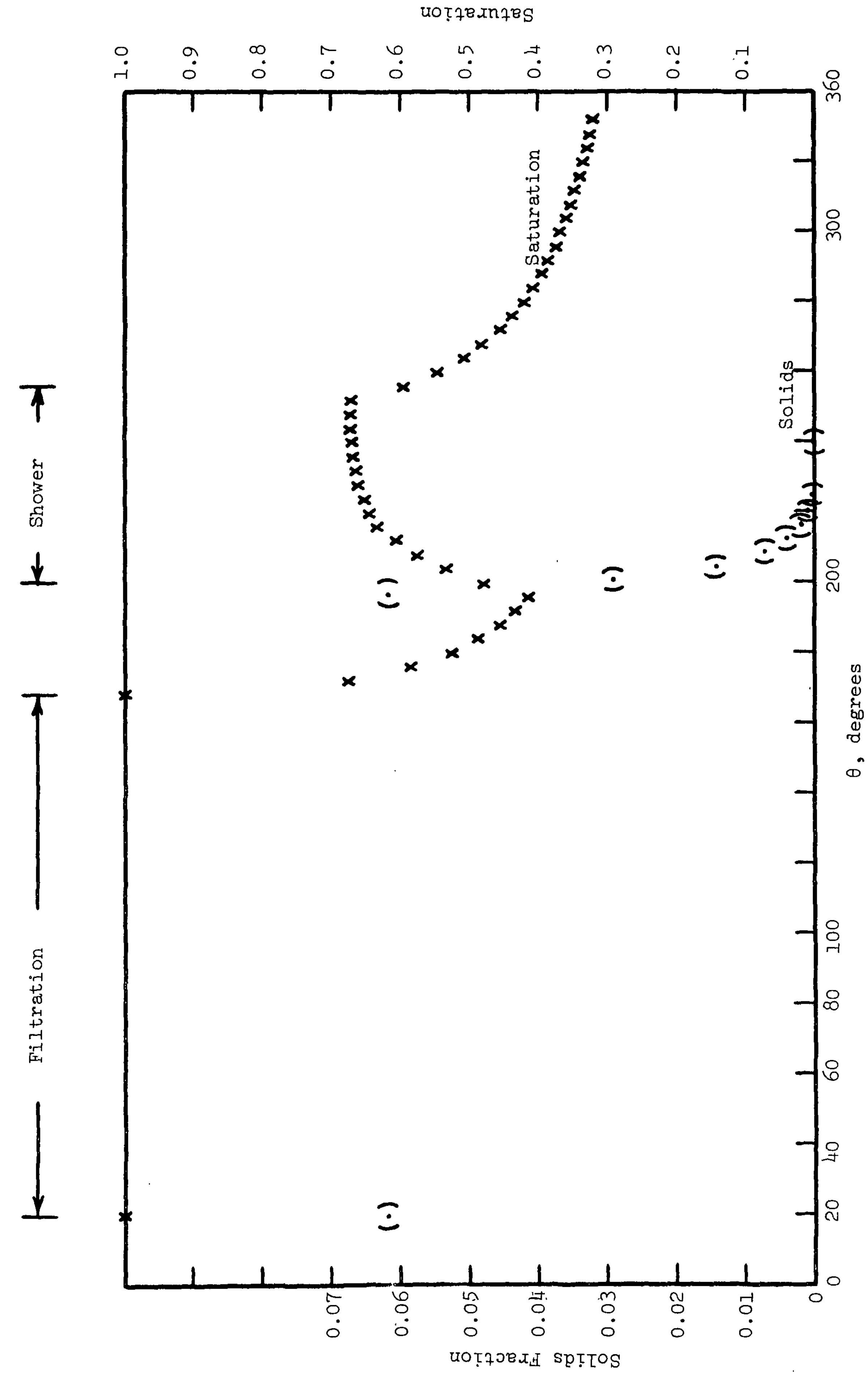

Figure 6. Solids Fraction and Saturation Along Contour Length of Drum

DISCUSSION

From a general viewpoint, the washer model appears to be successful. Critically speaking, it has not predicted actual results and has deficiencies in the solids balance. The basis weight and pad density are about twice that of the real washer, the drum speed and vat level appear low; however, the exit pad consistency is not too far off. I believe at this point it will be necessary to run a sensitivity analysis on the model with respect to the fiber characteristics such as compressibility coefficient, specific surface and volume, and also drum vacuum, before we condemn the model. Whether or not the sampled pulp is representative of the actual pulp conditions is a question.

Turning the visit to the mill, it was observed that the drum speed was about 1.9 r.p.m. Ten minutes later the speed was up to 4.0 r.p.m. and a short time later 2.2 r.p.m. This would indicate a sensitive system which is somewhat oscillatory. However, this author is aware of at least one mill where a vacuum drum washer in a bleach plant has no speed or level control and performs quite well, although it does have problems with major upsets in the system.

NOMENCLATURE

a_p	viscous resistance coefficient of pad
a_w	viscous resistance coefficient of septum
A_d	cross-sectional area of drum, ft.^{2}
A_s	cross-sectional area occupied by stock, ft.^{2}
A_v	cross-sectional area of vat, ft.^{2}
b_p	inertial resistance coefficient of pad
b_w	inertial resistance coefficient of septum
D_D	vacuum drum diameter, feet
D_v	vat diameter
i	number of logical sectors in drum
k	Kozeny factor
k_1	3.5 a constant
k_2	57.0 a constant
k_3	0.1 a constant
K	permeability
L	vat level, feet
L_o	vat level overflow
P_f	compacting stress, dynes/cm.^{2}
ΔP	pressure drop, dynes/cm.^{2}
ΔP_p	pressure drop across pad of fibers, dynes/cm.^{2}
ΔP_T	total pressure drop, dynes/cm.^{2}
ΔP_w	pressure drop across septum or wire, dynes/cm.^{2}
S_v	specific surface of fibers, cm.^{2}/cm.^{3} of fibers
S_w	specific surface of fibers, cm.^{2}/g.
t	time, sec.

T	pad thickness, cm.
U_o	filtrate velocity, cm./sec.
U_s	shower water velocity, cm./sec.
V	specific volume of fibers, $cm.^3$/g. o.d. fiber
W	mass of fibers (o.d.) in pad per unit area of septum, $g./cm.^2$
α	coefficient
β	coefficient
γ	surface tension, dynes/cm.
δ	sector length, cm.
$\bar{\varepsilon}$	average pad porosity, dimensionless
μ	fluid viscosity, poise
ρ	fluid density, $g./cm.^3$
ρ_p	pad density, g. o.d. fiber/$cm.^3$ of pad
θ	contact angle, degrees
θ_I	initial point for pad filtration
θ_E	exit point for pad
θ_F	final point for pad filtration
θ_P	point of pressure change
θ_{SB}	start point for shower
θ_{SE}	ending point for shower
σ	saturation
σ_R	residual saturation
σ_E	effective saturation
ω_D	drum speed, r.p.m.

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APPENDIX I

COMPUTER PROGRAM LISTING

```
C   MAINLINE PROGRAM FOR TESTING THE SUBROUTINES FOR THE VACUUM DRUM WAS
      INTEGER       DSPLC, BGNSHR,ENDSHR,SHRSTR
      REAL  K1,K2,M,N,LVLVAT,K3,H1,H2
      REAL  LVLOVR
      DIMENSION BW(359),RHOPAD(359),AO(359),BO(359),SAT(359),UO(359)
      DIMENSION SCONC(359),CONS(359)
      COMMON DIADRM,WIDTH,PDRUM,DIAVAT,PI,CONTOR,DTHETA
      COMMON GRAVC,RHOH2O,K1,K2,K3  ,FTCM,QWSHEX,QPAD ,QWASH ,FBROUT
      COMMON AOWIRE,BOWIRE ,M,N,SV,V,DELTIM,QFIL,QPADI
      COMMON BGNSHR,ENDSHR,DTIMS ,SHRSTR,KPART,KEXIT,KLAST,KSTART
      COMMON VATVSC,WSHVSC,LVLVAT,SLCVAT,QSHWR,SLCSHR,CNSVAT
      COMMON SLDFIL,SLDWSH,SLDPAD,SLCPAD,SLDOUT,CONST1,SLDIMD
      COMMON H1,H2,ALFA,BATA,JPOINT,DSPLC
      COMMON BW,RHOPAD,      SAT,UO,SCONC,CONS,AO,BO
C   TEMP-VISC EQN OF BINGHAM,'FLUIDITY AND PLASTICITY' P340+137
C    TEMP=DEG C        VISC=POISE
      VISC(T)=1./(2.1482*((T-8.435)+SQRT(8078.4+(T-8.435)**2))-120.)
C.......RESISTANCE COEFFICIENTS FOR WIRE SCREEN.......................
      AOWIRE = 9000.
      BOWIRE = 2.57
      GRAVC = 980.
      RHOH2O = 1.0
      GPMFT3 = 7.481
      FTCM =  12.*2.54
C.......COEFFICIENTS FOR PULP FILTRATION....................
      K1 = 3.5
      K2 = 57.0
      K3 = 0.1
      PI = 3.1415927
      JPOINT = 1
      DSPLC = 0
      LVLVAT = 0.
C........MODIFIED MASS TRANSFER COEFFICIENTS..................
      H1 = .0072
      H2 = .005
C...... CONSOLIDATED INC. VAT OVERFLO AND VOLUME.............
      LVLOVR = -1.584
      VOLOVR =  11.04*16.
C......KLAST CANNOT BE GREATER THAN 358 AND MUST BE EVEN.........
      KLAST = 358.
      KSTART = 1
C  WASHER AND PULP SPECIFICATIONS
      READ (5,501)DIADRM,WIDTH,PDRUM,DIAVAT,AOWIRE,BOWIRE
501   FORMAT(8E10.2)
      READ(5,501) RHOO,M,N,SV,V
      READ (5    ,501) QSTOCK,CNSTK,SLCSTK,TMPSTK
      CNSVAT = CNSTK
C  SHOWER CONFIG  AND PARAMETERS
      READ (5    ,502) KLAST,PART,BSHOWR,ESHOWR,EEXIT
502   FORMAT ( I5,4F5.0)
C.........CORRECTION FOR A BUG...............................
      IND = KLAST/2
      RHOPAD(IND)      = 0.004
      KPART = PART/360.*KLAST
      BGNSHR = BSHOWR/360.*KLAST
      ENDSHR = ESHOWR/360.*KLAST
      KEXIT =EEXIT/360.*KLAST
      READ (5    ,501) TMPWSH,QSHWR,SLCSHR
      SLDSHR = QSHWR*8.345*SLCSHR/(1. - SLCSHR)
```

```
      ALFA = 62.4*SLCSHR/(1. - SLCSHR)
      SHRSTR =  BGNSHR
      VOLVAT = PI*(DIAVAT**2 - DIADRM**2)/8.*WIDTH
      READ(5,501)TSTART,TFINAL,DELTAT
C............READ IN INITIAL CONDITIONS.............................
      READ (5,519)KKLAST,KSTART,LVLVAT,CNSVAT,SLCVAT,VOLVAT,SLDVAT,
     1FBRVAT
      IF (KKLAST - KLAST)25,30,25
   25 WRITE (6,510)
  510 FORMAT('OWARNING 02 - KLAST NOT SAME - STARTUP RUN')
      GO TO 35
   30 DO 35 J=1,KLAST
      READ (5,511)INDEX,BW(INDEX),SCONC(INDEX),CONS(INDEX),SAT(INDEX),
     1RHOPAD(INDEX),UO(INDEX),AO(INDEX),BO(INDEX)
   35 CONTINUE
      VATVSC = VISC(TMPSTK)
      WSHVSC = VISC(TMPWSH)
C............VACUUM IN DRUM IS IN INCHES OF HG......................
      PDRUM = -PDRUM*2.54*13.6*GRAVC
      DTHETA = 2.*PI/KLAST
      CONTOR = DIADRM*DTHETA/2.
      WRITE (6,583) CONTOR,KPART,BGNSHR,ENDSHR,KEXIT
  583 FORMAT ('1',E15.7,4I5)
      CONST1 = 30.48**2*WIDTH*PI*DIADRM/454.
      QSTOCK = QSTOCK/GPMFT3
      FBRIN = QSTOCK*62.4*CNSTK/(1.- CNSTK)
      FBRVAT = VOLVAT*62.4*CNSVAT/(1. - CNSVAT)
      SLDIN =(QSTOCK*62.4          )*SLCSTK/(1. - SLCSTK)
      WRITE (2,516)
  516 FORMAT ('1')
C ...... PROPORTIONAL + RESET CONTROL AT CONSOLIDATED..............
C...........RESET IS ZERO FOR NOW
   50 RPM = 3.5
      RPM = - LVLVAT + 3. + RESET
C..........COMPUTE DELTA T IN MINUTES AND THEN SECONDS................
      DELTIM = CONTOR/(RPM*PI*DIADRM)
      DTIMS = DELTIM*60.
      CALL VACDRM(1,RPM,DELTAT)
C........VOLUME BALANCE AROUND VAT...................................
      QSTCK = QSTOCK*DELTIM
      DVOL = QSTCK  - QPADI+ QWSHEX - QFIL
      VOLVAT = VOLVAT + DVOL
C........FIBER BALANCE AROUND VAT....................................
      FIBRN = FBRIN*DELTIM
      DFBR = FIBRN         - FBROUT
      FBRVAT = FBRVAT + DFBR
      IF (FBRVAT)53,54,54
   53 FBRVAT = 0
   54 CNSVAT = FBRVAT/(FBRVAT + VOLVAT*62.4)
C...........SOLIDS BALANCE AROUND VAT..............................
      SOLDIN = SLDIN*DELTIM
      DSLD = SOLDIN - SLDOUT - SLDIMD
      SLDVAT = SLDVAT + DSLD
      SLCVAT = SLDVAT/(VOLVAT*62.4 + SLDVAT)
      CAREA = VOLVAT/WIDTH
C     WRITE (6,539) FBRVAT,DFBR,VOLVAT,DVOL,SLDVAT
C539  FORMAT(' VAT' 5E15.6)
C     WRITE (6,540)QFIL,QWSHEX,QWASH,QPADI,QPAD
C540  FORMAT (' FLOWS'5E15.6)
      CALL VATLVL (1,CAREA,LVLVAT,DIAVAT,DIADRM)
```

```
C     WRITE (6,539) LVLVAT
C ..... LEVEL LIMITER.............................
      IF (LVLVAT - LVLOVR)55,60,60
   55 LVLVAT = LVLOVR
      OVRFLO = (VOLVAT - VOLOVR)*7.45
      VOLVAT = VOLOVR
      FBRVAT = VOLVAT*62.4*CNSVAT/(1. - CNSVAT)
      SLDVAT = VOLVAT*62.4*SLCVAT/(1. - SLCVAT)
60    QPAD =   QPAD*7.481/DELTIM
      QPADI = QPADI*7.481/DELTIM
      QFIL = QFIL*7.481/DELTIM
      QWASH =  QWASH*7.481/DELTIM
      QTOT =            QWASH  + QFIL
      QSTCKG= QSTOCK*GPMFT3
      QWSHX  = QWSHEX*GPMFT3/DELTIM
      INDEX = KPOINT(KEXIT+1,KSTART,KLAST)
      FIBRO = FBROUT/DELTIM
      BWOUT = BW(INDEX)
      PADOUT = BWOUT*CONST1*RPM
      CNSOUT = CONS(INDEX)
      SATOUT = SAT(INDEX)
      SLCPAD = SCONC(INDEX)
      SLDFIL = SLDFIL/DELTIM
      SLDOUT = SLDOUT/DELTIM
      SLDWSH = SLDWSH/DELTIM
      SLDIMD = SLDIMD/DELTIM
      SLDPAD = PADOUT*SLCPAD*(1.- CNSOUT)/CNSOUT/(1. - SLCPAD)
      RPADOT = RHOPAD(INDEX)
      IF (RPADOT)64,64,63
  63  THICK = BWOUT/RPADOT
      GO TO 65
  64  THICK = 0.
  65  TIME = TIME + DELTIM
      PTIME = PTIME + DELTIM
      IF (PTIME - DELTAT) 50,90,90
  90  WRITE(02,512)TIME, RPM  ,LVLVAT,CNSVAT,SLCVAT
 512  FORMAT('0TIME ='F6.4,2X 'RPM  = ',F7.3,7X,'LVLVAT ='F7.3,9X,
     1'CNSVAT='F7.4, 8X,'SLDVAT='F7.3)
      WRITE (02,513)QSTCKG,QFIL,QPADI,QWSHEX
 513  FORMAT(15X,'QSTOCK ='F7.1,6X'QFIL =', F7.1,11X,'QPADI =',F7.2
     1, 8X,'QWSHEX = 'F7.2)
      WRITE (2,514) QTOT,QPAD,QWASH,QSHWR
 514  FORMAT(15X,'QTOT ='  ,F7.1,8X,'QPAD ='F7.2,11X,'QWASH =',F7.1,9X,
     1'QSHWR =',F7.2)
      WRITE (2,515)FBRIN,FIBRO,BWOUT,SATOUT
 515  FORMAT (15X,'FIBER IN ='F7.2, 4X,'FIBER OUT =',F7.2, 6X,'BWOUT ='
     1,F7.5, 8X,'SATOUT =',F7.4)
      WRITE (2,517) PADOUT,RPADOT,CNSOUT,THICK
 517  FORMAT (15X,'PADOUT ='F7.2, 6X,'RPADOUT =',F7.5, 8X,'CNSOUT ='
     1,F7.4, 8X,'THICKNESS =',F7.3)
      WRITE (2,518)SLDIN ,SLDFIL, SLDPAD, SLDWSH
  518 FORMAT(15X,'SLDIN  =',F7.2, 6X,'SLDFIL =',F7.2, 9X,'SLDPAD =',F7.3
     1,8X,'SLDWSH =',F7.3)
      WRITE (2    ,5181)SLDOUT,SLDIMD,SLDSHR
 5181 FORMAT(15X,'SLDOUT =',F7.2,6X,'SLDIMD =',F7.2,9X,'SLDSHR =',F7.2)
      PTIME = 0
  170 IF (TIME -TFINAL)50,180,180
 180  WRITE (10,519) KLAST,KSTART,LVLVAT,CNSVAT,SLCVAT,VOLVAT,SLDVAT,
     1FBRVAT
  519 FORMAT (' ',2I5,F7.3,F6.4,F6.4,3E14.7)
```

```
      DO 200 J=1,KLAST
190   INDEX = KPOINT(J,KSTART,KLAST)
      WRITE(10,511)INDEX,BW(INDEX),SCONC(INDEX),CONS(INDEX),SAT(INDEX),
     1RHOPAD(INDEX),UO(INDEX),AO(INDEX),BO(INDEX)
511   FORMAT(I3, F9.6,3F6.4,F6.5, F6.3,2E14.7)
200   CONTINUE
      END FILE 2
      CALL EXIT
      END
      SUBROUTINE VACDRM(L,RPM,DELTAT)
C...........VACUUM DRUM PULP WASHER ..............................
      INTEGER FILIN,FILOUT,BGNSHR,ENDSHR,SHRSTR,DSPLAC,DSPLC
      REAL  K1,K2,M,N,LVLVAT,K3,H1,H2
      DIMENSION BW(359),RHOPAD(359),AO(359),BO(359),SAT(359),UO(359)
      DIMENSION SCONC(359),CONS(359)
      COMMON DIADRM,WIDTH,PDRUM,DIAVAT,PI,CONTOR,DTHETA
      COMMON GRAVC,RHOH2O,K1,K2,K3  ,FTCM,QWSHEX,QPAD ,QWASH ,FBROUT
      COMMON AOWIRE,BOWIRE ,M,N,SV,V,DELTIM,QFIL,QPADI
      COMMON BGNSHR,ENDSHR,DTIMS ,SHRSTR,KPART,KEXIT,KLAST,KSTART
      COMMON VATVSC,WSHVSC,LVLVAT,SLCVAT,QSHWR,SLCSHR,CNSVAT
      COMMON SLDFIL,SLDWSH,SLDPAD,SLCPAD,SLDOUT,CONST1,SLDIMD
      COMMON H1,H2,ALFA,BATA,JPOINT,DSPLC
      COMMON BW,RHOPAD,      SAT,UO,SCONC,CONS,AO,BO
      JI = JI + 1
      DSPLAC = 0
C........COMPUTE BEGINING, ENDING, AND NUMBER OF SEGMENTS FOR ..........
C........               FILTRATION                            ..........
      THETAI = ATAN(ABS(LVLVAT*2./DIADRM))
      FILIN = 1. + SIGN(THETAI*DIADRM/(2.*CONTOR),LVLVAT)
      FILOUT = KLAST/2  + 1  - FILIN
      NSEG = FILOUT - FILIN + 1
      NSG = FILIN + KLAST - KEXIT
      IF (FILIN)150,150,160
150   DSPLAC  = KLAST
160   FILIN = FILIN + DSPLAC
C     IF (JI -26)170,165,165
C165  WRITE (6,576) LVLVAT,THETAI,FILIN,FILOUT,DSPLAC
C576  FORMAT(' ',2E15.6,3I5)
 170  QPAD  = 0
      QPADI = 0
      QFIL = 0
      QWASH  = 0
      SLDFIL = 0
      SLDWSH = 0
      FBROUT = 0
      SLDOUT = 0
      QWSHEX = 0
      FBRSUM = 0
      QOUT = 0
      KRAMP = 0
      QPADT=  0.
      QWASHT= 0
C..........PAD FORMATION SECTION ........................
C.........        C G S  SYSTEM OF UNITS IS USED HERE  .......
      DO 290  J=1,NSEG
      K = J + FILIN - 1
 220  INDEX = KPOINT(K,KSTART,KLAST)
C     IF (JI - 26)230,221,221
C221  WRITE (6,577) J,K,INDEX,FILIN,FILOUT,KSTART
C577  FORMAT(' '6I5)
```

```
230    IF (K - KPART)232,231,231
231    IF (K - FILOUT)235,235,232
232    PVAC = -1.0*GRAVC
       GO TO 239
C...........RAMP FUNCTION FOR INCREASING VACUUM...................
235    IF(KRAMP - 2 )236,237,237
236    KRAMP = KRAMP + 1
237    PVAC = PDRUM*KRAMP/2.
239    C = PVAC
       UOSAVE = 0.001
       IF (BW(INDEX))240,240,250
240    B = AOWIRE*VATVSC
       A = BOWIRE*RHOH2O
       SAT(INDEX) = 1.0
       GO TO 260
250    PSEPTM = VATVSC*AOWIRE*UO(INDEX)+RHOH2O*BOWIRE*UO(INDEX)**2 + PVAC
251    PSPTM = -PSEPTM
2521   RHOPAD(INDEX) = (1-N/2.)**2*M*( PSPTM )**N
       POR = 1 - V*RHOPAD(INDEX)
       REG3 = 1. - POR
       IF(POR - 0.7)253,254,254
253    ALPHA = 5.60
       GO TO 255
254    ALPHA = K1*POR**3*(1.+K2*REG3**3)/SQRT(REG3)
255    BETA = K3*SQRT(ALPHA)
       AO(INDEX) = ALPHA*REG3**2*SV**2/POR**3
       BO(INDEX) = BETA*REG3*SV    /POR**3
       WB = BW(INDEX) + UO(INDEX)*DTIMS *CNSVAT/(1.-CNSVAT)
       B = (AO(INDEX)*WB/RHOPAD(INDEX)+AOWIRE)*VATVSC
       A = (BO(INDEX)*WB/RHOPAD(INDEX)+BOWIRE)*RHOH2O
       UOSAVE = UO(INDEX)
260    UO(INDEX)=(-B+SQRT(B**2-4.*A*C))/(2.*A)
 261   IF(ABS(UO(INDEX)-UOSAVE)/UOSAVE - 0.01)262 ,262 ,250
C2611 IF (JI - 27)262,2612,2612
C2612 WRITE (6,587) INDEX,BW(INDEX),RHOPAD(INDEX),A,B,WB,UO(INDEX),PSPTM
C587   FORMAT( I5,7E11.4)
C      UO(INDEX) = 0.001
C      GO TO 250
262    QOUT = QOUT + UO(INDEX)
290    CONTINUE
C      IF (JI - 26)294,293,293
C293   WRITE (6,567)INDEX,BW(INDEX),CONS(INDEX),SAT(INDEX),RHOPAD(INDEX)
C     1,UO(INDEX)
C567   FORMAT(' FILOUT',I5,5E12.4)
294    QPADT=          QOUT
C..........PREPAD CONDITIONS ABOVE VAT LEVEL .....................
       IF(NSG)350,350,310
310    DO 350 J=2,NSG
       K = J + KEXIT - 1
320    INDEX = KPOINT(K,KSTART,KLAST)
340    UO(INDEX) = 0.
350    CONTINUE
C.......TWO PHASE FLOW AND WASHING (OR LEECHING) SECTION..............
       KBGIN  = FILOUT + 1
       QOUT = 0
 370   CALL TFFLO(L,KBGIN,QWASHT,QOUT)
       QPADT = QPADT + QOUT
C.......UPDATE BASIS WEIGHT AND SOLIDS .................................
       DO 539 J=1,KEXIT
       K = J + FILIN - 1
```

```
510    INDEX = KPOINT(K,KSTART,KLAST)
       IF (J - NSEG)511,511,535
511    FIBER = UO(INDEX)*CNSVAT*DTIMS /(1. - CNSVAT)
       BWSAV = BW(INDEX)
       CNSAV = CONS(INDEX)
       SLCSAV = SCONC(INDEX)
       FBRSUM = FBRSUM + FIBER
530    BW(INDEX) = BW(INDEX) + FIBER
       PADVOL = BW(INDEX)/RHOPAD(INDEX)
       FRACT = UO(INDEX)*DTIMS
       IF (FRACT - PADVOL)531,531,533
  531 SCONC(INDEX) = (FRACT*SLCVAT + (PADVOL - FRACT)*SLCSAV)/PADVOL
       SOLIDS = FRACT*SLCSAV/(1. - SLCSAV)
       GO TO 534
  533 SCONC(INDEX) = SLCVAT
       SOLIDS = PADVOL*SLCSAV/(1. - SLCSAV) + (FRACT - PADVOL)*SLCVAT
      1/(1. - SLCVAT)
  534 SLDOUT =  SLDOUT + UO(INDEX)*DTIMS*SLCVAT/(1. - SLCVAT)
       SLCFIL = SLDFIL + SOLIDS
       GO TO 535
 536   CONS(INDEX) = CNSVAT
       GO TO 539
 535   IF(RHOPAD(INDEX))536,536,538
 538   PADVOL = BW(INDEX)/RHOPAD(INDEX)
       WATER = SAT(INDEX)*(1. - V*RHOPAD(INDEX))*PADVOL + (V-0.614)*
      1BW(INDEX)
       CONS(INDEX) = BW(INDEX)/(WATER + BW(INDEX))
 539   CONTINUE
       FBROUT =            FBRSUM*30.48**2*CONTOR*WIDTH/454.
       SLDOUT = SLDOUT*30.48**2*CONTOR*WIDTH/454.
       SLDFIL = SLDFIL*30.48**2*CONTOR*WIDTH/454.
        SLDWSH = SLDWSH*30.48**2*CONTOR*WIDTH/454.
C....... COMPUTE INTERMEDIATE FLOWS.........................
       INDEX = KPOINT(BGNSHR-1,KSTART,KLAST)
       QPADI=          BW(INDEX)*(1.-CONS(INDEX))/CONS(INDEX)
       SLCIMD = SCONC(INDEX)
C........COMPUTE OUTPUT  FLOWS ..........................
       INDEX = KPOINT(KEXIT,KSTART,KLAST)
       QPAD =          BW(INDEX)*(1.- CONS(INDEX))/CONS(INDEX)
C.......SHIFT POINTER (INDEX) FOR NEXT TIME STEP......................
       IF(KSTART-1)540,540,550
540    KSTART = KLAST + 1
550    KSTART = KSTART - 1
C............CLEAN OFF EXIT SIDE OF DRUM.............................
       DO 600 J=2,NSG
       K = KEXIT + J
       INDEX = KPOINT(K,KSTART,KLAST)
       UO(INDEX) = 0
       SCONC(INDEX)=SLCVAT
       SAT(INDEX) = 1.
       BW(INDEX) = 0.
       RHOPAD(INDEX) = 0.
       CONS(INDEX) = CNSVAT
600    CONTINUE
       QFIL = QPADT*CONTOR*WIDTH*DTIMS/30.48
       QWASH = QWASHT*CONTOR*WIDTH*DTIMS/30.48
       QPADI = QPADI*CONST1*DELTIM*RPM/62.4
       QPAD = QPAD*CONST1*DELTIM*RPM/62.4
       SLDIMD = QPADI*62.4*SLCIMD/(1. - SLCIMD)
       RETURN
```

```
      END
      SUBROUTINE TFFLO(L,KBGN ,QWASHT,QOUT)
C........ TWO PHASE FLOW SUBROUTINE WITH SHOWER WASH...............
      INTEGER        DSPLC, BGNSHR,ENDSHR,SHRSTR
      REAL  K1,K2,M,N,LVLVAT,K3,H1,H2
      DIMENSION BW(359),RHOPAD(359),AO(359),BO(359),SAT(359),UO(359)
      DIMENSION SCONC(359),CONS(359)
      COMMON DIADRM,WIDTH,PDRUM,DIAVAT,PI,CONTOR,DTHETA
      COMMON GRAVC,RHOH2O,K1,K2,K3   ,FTCM,QWSHEX,QPAD ,QWASH ,FBROUT
      COMMON AOWIRE,BOWIRE ,M,N,SV,V,DELTIM,QFIL,QPADI
      COMMON BGNSHR,ENDSHR,DTIMS ,SHRSTR,KPART,KEXIT,KLAST,KSTART
      COMMON  VATVSC,WSHVSC,LVLVAT,SLCVAT,QSHWR,SLCSHR,CNSVAT
      COMMON SLDFIL,SLDWSH,SLDPAD,SLCPAD,SLDOUT,CONST1,SLDIMD
      COMMON H1,H2,ALFA,BATA,JPOINT,DSPLC
      COMMON BW,RHOPAD,      SAT,UO,SCONC,CONS,AO,BO
C..............COMPUTE SHOWER WATER VELOCITY PENETRATING PAD............
C..............   ASSUMING  U=Q/A    ...................................
      USHWR = (QSHWR*3785./60.+EXSHWR          )/((ENDSHR-BGNSHR+1)*
     1CONTOR*WIDTH*FTCM**2)
      EXSHWR = 0.
      QWASHT = 0.
      QOUT   = 0
      NSGMTS = ENDSHR  - BGNSHR  + 1
      CONANG = 10.
      CONANG = CONANG*PI/18C.
      GAMMA = 35.
C.......... IMPCO SAYS EFFECTIVE VACUUM AT INSIDE OF DRUM IS...........
C...........     ABOUT 3/4 OF INDICATED VACUUM               ...........
C....... HOWEVER JFP THINKS THIS IS ACCOUNTED FOR IN EFFECTIVE PAD
C.......       PRESSURE DROP
      PDRUM2 = 1.00*PDRUM
      DO 900 J=KBGN,KEXIT
      INDEX = KPOINT(J,KSTART,KLAST)
120   IF (BW(INDEX))900,900,1210
1210  RHOPD = RHOPAD(INDEX)
      PORO = 1.-V*RHOPD
      VPAD = BW(INDEX)/RHOPD
      RHOPAD(INDEX) = (1.-N/2.)**2*M*(-PDRUM2)**N
      PORVOL = 1. - V*RHOPAD(INDEX)
      VPAD = BW(INDEX)/RHOPAD(INDEX)
      REG1 = PORVOL*VPAD
C     WRITE (6,560) J, INDEX,RHOPAD(INDEX),PORO,VPAD,SAT(INDEX),RHOPD
C560  FORMAT(' '2I5,5E12.4)
      SAT(INDEX) = SAT(INDEX)*PORO*VPAD/REG1
C  RESIDUAL SATURATION COMPUTATION ACCORDING TO BROWNELL AND KATZ
C     REF.  CHEM ENG. PROG. VOL 47(    ),P
      CAPNUM =-PDRUM2*RHOPAD(INDEX)/(AO(INDEX)*BW(INDEX)*GAMMA*
     1 COS(CONANG))
      RSDSAT = CAPNUM**(-0.264)/86.3
      FXDSAT = (1.-SAT(INDEX))*RSDSAT/(1. - RSDSAT)
      EFVSAT = (SAT(INDEX)-RSDSAT)/(1.-2.*RSDSAT + RSDSAT*SAT(INDEX))
C........... EFFECTIVE PAD PRESSURE DROP ..........................
C  REF. SWEENEY - AICHE JOURN   V.13,N.4,P663-9 (JULY,1967)
      PVAC = PDRUM2*EFVSAT**3
      B = (AO(INDEX)*BW(INDEX)/RHOPAD(INDEX)+AOWIRE)
      A = (BO(INDEX)*BW(INDEX)/RHOPAD(INDEX)+BOWIRE)*RHOH2O
C     WRITE (6,519) INDEX, PVAC,BW(INDEX),CAPNUM
C519  FORMAT(1H ,I5,6E12.4)
      IF (J - BGNSHR)125,122,122
122   IF(J - ENDSHR)200,200,125
```

```
125    IF (SAT(INDEX))140,140,126
126    IF(J-ENDSHR)127,127,128
127    UO(INDEX) =(-B*VATVSC + SQRT((B*VATVSC)**2-4.*A*PVAC))/(2.*A)
C      WRITE (6,550)
C550   FORMAT(' 127')
       GO TO 129
128    UO(INDEX) =(-B*WSHVSC + SQRT((B*WSHVSC)**2-4.*A*PVAC))/(2.*A)
C      WRITE (6,551)
C551   FORMAT(' 128')
129    SATUR      = (REG1*SAT(INDEX)-UO(INDEX)*DTIMS )/REG1
C      WRITE (6,522) UO(INDEX),SATUR,SAT(INDEX),RSDSAT,FXDSAT,EFVSAT
C522   FORMAT(1H ,6E13.5)
       IF (SAT(INDEX)-RSDSAT)130,130,131
131    SAT(INDEX) = SATUR
       GO TO 800
130    UO(INDEX) = REG1*(SAT(INDEX) - RSDSAT)/DTIMS
       SAT(INDEX) = RSDSAT
       GO TO 800
140    UO(INDEX) = 0
       GO TO 800
C.......INTRODUCE SHOWER WATER ON PAD...............................
200    SATSAV = SAT(INDEX)
       SLCSAV = SCONC(INDEX)
       IF(SAT(INDEX)-1.)250,220,220
220    UO(INDEX)=(-B*VATVSC + SQRT((B*VATVSC)**2-4.*A*PDRUM2))/(2.*A)
       TEMP = USHWR - UO(INDEX)
       USHR = USHWR
       IF(TEMP)230,300,240
230    SATUR      = (REG1*SAT(INDEX) + TEMP*DTIMS )/REG1
       IF (SAT(INDEX)-RSDSAT)231,232,232
231    UO(INDEX) = REG1*(SAT(INDEX)-RSDSAT)/DTIMS
       SAT(INDEX) = RSDSAT
       GO TO 300
232    SAT(INDEX) = SATUR
       GO TO 300
240    EXSHWR = EXSHWR + TEMP
       USHR = UO(INDEX)
       GO TO 300
250    IF (SAT(INDEX)-RSDSAT)251,251,252
 251   UO(INDEX) = 0
       USHR = USHWR
       GO TO 270
252    UO(INDEX)=(-B*WSHVSC + SQRT((B*WSHVSC)**2-4.*A*PVAC))/(2.*A)
       UMXSHR = REG1*(1.-SAT(INDEX))/DTIMS  + UO(INDEX)
       USHR = USHWR
       IF(USHWR - UMXSHR)270,265,260
260    EXSHWR = EXSHWR + (USHWR-UMXSHR)
       USHR = UMXSHR
265    SAT(INDEX) = 1.
       GO TO 300
270    SAT(INDEX) = (REG1*SAT(INDEX)-(UO(INDEX)-USHWR)*DTIMS )/REG1
C............. SOLIDS COMPUTATION FOR WASHING SECTION.................
C...........COMPLETE MIXING MODEL    J.F. PERRY  27 JUL 1970.......
 300   SIN = USHR*DTIMS*SLCSHR/(1.-SLCSHR)
       SLDS = REG1*SATSAV*SLCSAV/(1. - SLCSAV) + SIN
        SLC =(SIN + SLDS)/(REG1*SATSAV + USHR*DTIMS)
        SOUT = UO(INDEX)*DTIMS*SLC/(1.-SLC)
        SLCS = SLDS - SOUT
       BSLDS = 0
       WATER = SAT(INDEX)*PORVOL*VPAD + (V - 0.614)*BW(INDEX)
```

```
      SCONC(INDEX) = (SLDS + BSLDS)/(SLDS + BSLDS + WATER)
C...........ACCUMULATE FILTRATE AND WASH WATERS.....................
800   IF(J - BGNSHR)810,820,820
810   QOUT = QOUT + UO(INDEX)
       SLDFIL = SLDFIL + UO(INDEX)*DTIMS*SCONC(INDEX)/(1.-SCONC(INDEX))
      GO TO 900
820   QWASHT = QWASHT + UO(INDEX)
      SLDWSH = SLDWSH + SOUT
C......IF THERE IS ANY EXCESS SHOWER WATER INCREASE SHOWER AREA......
C......  ON COUNTER ROTATION SIDE OF DRUM (WATER FALLS DOWN HILL ONLY)
900   CONTINUE
910   IF (EXSHWR)940,940,920
920   IF (BGNSHR-KBGN)935,935,930
930   BGNSHR = BGNSHR - 1
      EXSHWR = EXSHWR*CONTOR*WIDTH*30.48**2
      GO TO 1000
C.......WHEN AREA REACHES VAT LEVEL THE REMAINDER IS EXCESS ...........
C........    WHICH FLOWS INTO VAT                          ...........
935   QWSHEX = EXSHWR*WIDTH*CONTOR*DTIMS/30.48
      EXSHWR = 0.
      GO TO 1000
940   IF (BGNSHR-SHRSTR)950,1C00,1000
950   BGNSHR = BGNSHR + 1
      CWSHEX = 0
1000  CONTINUE
      RETURN
      END
      FUNCTION KPOINT(J,KSTART,KLAST)
      J = MOD(J,KLAST)
      IF (J)10,8,10
 8    J = KLAST
10    KPOINT= KSTART + J-1-DSPLAC
      KPOINT = MOD(KPOINT,KLAST)
      IF (KPOINT)20,20,30
20    KPOINT = KLAST
30    RETURN
      END
      SUBROUTINE VATLVL(L,CAREA ,LVLVAT,VD,DD)
C.....SUBROUTINE FOR COMPUTING THE LEVEL IN A VACUUM DRUM WASHER
C.....L        RESERVED FOR FUTURE WORK (WASHER NO.)
C.....CAREA    CROSS SECTIONAL AREA BETWEEN DRUM AND VAT, FT**2
C.....LVLVAT   LEVEL OF STOCK IN VAT OF WASHER, FT
C.....VD       EQUIVALENT DIAMETER OF VAT FLOOR OF WASHER, FT
C.....DD       DIAMETER OF DRUM, FT
      REAL LVLVAT
      PI = 3.1415927
      AREAS = CAREA
      R5 = DD**2/4.
      R4 = VD**2/4.
      IF (LVLVAT)72,10,10
10    R3 = LVLVAT**2
      R2 = DIM(R5,R3)
      R1 = DIM(R4,R3)
      Z1 = SQRT(R1)
      Z2 = SQRT(R2)
      OLVLVT = LVLVAT
C.......COMPUTE THEORETICAL AREA BASED ON PREVIOUS LEVEL
      AREAV = PI*R4/2. - LVLVAT*Z1 - R4*ATAN(LVLVAT/Z1)
      AREAD = 0
      IF (R2)30,30,20
```

```
20    AREAD = PI*R5/2. - LVLVAT*Z2 - R5*ATAN(LVLVAT/Z2)
30    FUNC = AREAS  - (AREAV - AREAD)
      IF (FUNC)40,90,40
C......COMPUTE DERIVATIVE OF AREA WITH RESPECT TO LEVEL
40    DFUNC  =-Z1 + R3/Z1 - R4*(R3/R1**(3./2.) + 1./Z1)/(1. + R3/R1)
      IF (R2)60,60,50
50    DFUNC  = DFUNC +Z2 -R3/Z2 + R5*(R3/R2**(3./2.) +1./Z2)/(1.+R3/R2)
C...... COMPUTE INCREMENTAL CHANGE IN LEVEL
60    DLVL = FUNC /DFUNC
      LVLVAT = LVLVAT + DLVL
C...... IF ABS DIFF BETWEEN PREVIOUS AND NEW LEVEL IS LESS THAN
C......   THEN  ACCEPT THE NEW LEVEL AND EXIT, OTHERWISE REITERATE
      IF (ABS( OLVLVT - LVLVAT)  - .01)90,90,69
C......IF LEVEL GOES ABOVE DRUM AXIS (IE. NEG) INVERT PROBLEM AND RECOMP
69    IF (LVLVAT)70,10,10
 70   IF (SLVLVT)71,72,72
 71   SLVLVT = -LVLVAT
      LVLVAT = - LVLVAT
      AREAS = CAREA
      GO TO 10
72    SLVLVT = LVLVAT
      LVLVAT = - LVLVAT
      AREAS = PI*(R4 - R5) - AREAS
      GO TO 10
90    IF (SLVLVT)95,99,99
95    LVLVAT = - LVLVAT
99    RETURN
      END
```

APPENDIX II

SAMPLE DATA

```
11.5       16.0       8.0          12.5      595.      2.69
0.         0.001345   0.386       2975.     3.09
5370.       0.01       0.06         82.
  090   75. 200. 250. 330.
67.         350.       0.0
0.          2.00       0.05
    90   70  2.0040.01090.0621 0.1181022E 03 0.4879551E 03 0.8148511E 02
 70 0.0       0.06210.01091.0000.0      0.0   0.1959765E 08 0.8226243E 03
 71 0.0       0.06210.01091.0000.0      0.0   0.1959765E 08 0.8226243E 03
 72 0.0       0.06210.01091.0000.0      0.0   0.1959765E 08 0.8226243E 03
 73 0.0       0.06210.01091.0CC0.0      0.0   0.1959765E 08 0.8226243E 03
 74 0.0       0.06210.01091.0000.0      0.0   0.1959765E 08 0.8226243E 03
 75 0.0098550.06210.01221.0000.01227 1.331 0.2294431E 06 0.5075978E 02
 76 0.0161860.06210.01231.0000.01236 0.855 0.2320318E 06 0.5106786E 02
 77 0.0211190.06210.01231.000C.01240 0.666 0.2329703E 06 0.5117920E 02
 78 0.0252740.06210.01241.0000.01241 0.561 0.2334596E 06 0.5123715E 02
 79 0.0289280.06210.01241.0000.01243 0.494 0.2337931E 06 0.5127666E 02
 80 0.0322230.06210.01241.0000.01243 0.445 0.2340266E 06 0.5130429E 02
 81 0.0352480.06210.01241.0000.01244 0.409 0.2342168E 06 0.5132678E 02
 82 0.0380560.06210.01241.0C00.01244 0.379 0.2343496E 06 0.5134248E 02
 83 0.0406870.06210.01241.0C00.01245 0.356 0.2344581E 06 0.5135533E 02
 84 0.0431720.06210.01241.0000.01245 0.336 0.2345492E 06 0.5136609E 02
 85 0.0455310.06210.01241.0000.01245 0.319 0.2346264E 06 0.5137521E 02
 86 0.0477810.06210.01241.0000.01246 0.304 0.2346934E 06 0.5138313E 02
 87 0.0499380.06210.01241.000C.01246 0.291 0.2347523E 06 0.5139008E 02
 88 0.0833020.06210.08111.0000.08376 4.508 0.8110437E 07 0.4463159E 03
 89 0.1110630.06210.10511.0000.10949 3.751 0.1958635E 08 0.8222842E 03
 90 0.1341680.06210.10511.0000.10950 3.122 0.1958917E 08 0.8223694E 03
  1 0.1543590.06210.10511.00CC.10950 2.728 0.1959109E 08 0.8224270E 03
  2 0.1724890.06210.10511.0000.10950 2.450 0.1959234E 08 0.8224644E 03
  3 0.1890840.06210.10511.0000.10951 2.242 0.1959328E 08 0.8224932E 03
  4 0.2044560.06210.10511.000C.10951 2.077 0.1959392E 08 0.8225122E 03
  5 0.2188380.06210.10511.000C.10951 1.943 0.1959445E 08 0.8225278E 03
  6 0.2323980.06210.10511.0000.10951 1.832 0.1959494E 08 0.8225430E 03
  7 0.2452600.06210.10511.0000.10951 1.738 0.1959531E 08 0.8225542E 03
  8 0.2575210.06210.10511.0000.10951 1.657 0.1959565E 08 0.8225645E 03
  9 0.2692570.06210.10511.00CC.10951 1.586 0.1959592E 08 0.8225725E 03
 10 0.2805300.06210.10511.0000.10951 1.523 0.1959610E 08 0.8225776E 03
 11 0.2913890.06210.10511.C000.10951 1.467 0.1959637E 08 0.8225854E 03
 12 0.3018780.06210.10511.0000.10951 1.417 0.1959651E 08 0.8225901E 03
 13 0.3120300.06210.10511.0000.10951 1.372 0.1959670E 08 0.8225959E 03
```

14	0.3218770.06210.10511.0000.10951	1.330	0.1959685E	08	0.8226006E	03
15	0.3314440.06210.10511.0000.10951	1.293	0.1959706E	08	0.8226067E	03
16	0.3407530.06210.10511.0000.10951	1.258	0.1959712E	08	0.8226086E	03
17	0.3498240.06210.10511.0000.10951	1.226	0.1959723E	08	0.8226118E	03
18	0.3586750.06210.10511.0000.10951	1.196	0.1959738E	08	0.8226165E	03
19	0.3673200.06210.10511.0000.10951	1.168	0.1959750E	08	0.8226204E	03
20	0.3757730.06210.10511.0000.10951	1.142	0.1959757E	08	0.8226223E	03
21	0.3840460.06210.10511.0000.10951	1.118	0.1959765E	08	0.8226243E	03
22	0.3840460.06210.13210.6775.10952	1.118	0.1959765E	08	0.8226243E	03
23	0.3840460.06210.14290.5832.10952	0.327	0.1959765E	08	0.8226243E	03
24	0.3840470.06210.15020.5271.10952	0.195	0.1959765E	08	0.8226243E	03
25	0.3840460.06210.15560.4882.10952	0.135	0.1959765E	08	0.8226243E	03
26	0.3840460.06210.16000.4590.10952	0.101	0.1959765E	08	0.8226243E	03
27	0.3840470.06210.16370.4361.10952	0.080	0.1959765E	08	0.8226243E	03
28	0.3840470.06210.16670.4174.10952	0.065	0.1959765E	08	0.8226243E	03
29	0.3840470.02930.15670.4808.10952	0.045	0.1959765E	08	0.8226243E	03
30	0.3840470.01450.14920.5344.10952	0.078	0.1959765E	08	0.8226243E	03
31	0.3840470.00750.14360.5771.10952	0.117	0.1959765E	08	0.8226243E	03
32	0.3840470.00400.13980.6089.10952	0.154	0.1959765E	08	0.8226243E	03
33	0.3840470.00210.13720.6314.10952	0.186	0.1959765E	08	0.8226243E	03
34	0.3840460.00120.13550.6467.10952	0.211	0.1959765E	08	0.8226243E	03
35	0.3840470.00060.13430.6567.10952	0.229	0.1959765E	08	0.8226243E	03
36	0.3840470.00040.13360.6632.10952	0.242	0.1959765E	08	0.8226243E	03
37	0.3840470.00020.13320.6673.10952	0.250	0.1959765E	08	0.8226243E	03
38	0.3840470.00010.13290.6699.10952	0.255	0.1959765E	08	0.8226243E	03
39	0.3840470.00010.13280.6715.10952	0.259	0.1959765E	08	0.8226243E	03
40	0.3840470.00000.13270.6725.10952	0.261	0.1959765E	08	0.8226243E	03
41	0.3840470.00000.13260.6731.10952	0.262	0.1959765E	08	0.8226243E	03
42	0.3840470.00000.13250.6735.10952	0.263	0.1959765E	08	0.8226243E	03
43	0.3840470.00000.14110.5974.10952	0.263	0.1959765E	08	0.8226243E	03
44	0.3840470.00000.14750.5472.10952	0.174	0.1959765E	08	0.8226243E	03
45	0.3840470.00000.15240.5105.10952	0.127	0.1959765E	08	0.8226243E	03
46	0.3840470.00000.15650.4821.10952	0.098	0.1959765E	08	0.8226243E	03
47	0.3840470.00000.16000.4593.10952	0.079	0.1959765E	08	0.8226243E	03
48	0.3840460.00000.16300.4404.10952	0.066	0.1959765E	08	0.8226243E	03
49	0.3840470.00000.16560.4244.10952	0.055	0.1959765E	08	0.8226243E	03
50	0.3840460.00000.16790.4106.10952	0.048	0.1959765E	08	0.8226243E	03
51	0.3840460.00000.17000.3986.10952	0.042	0.1959765E	08	0.8226243E	03
52	0.3840460.00000.17180.3880.10952	0.037	0.1959765E	08	0.8226243E	03
53	0.3840460.00000.17350.3785.10952	0.033	0.1959765E	08	0.8226243E	03
54	0.3840460.00000.17510.3700.10952	0.030	0.1959765E	08	0.8226243E	03
55	0.3840460.00000.17650.3623.10952	0.027	0.1959765E	08	0.8226243E	03
56	0.3840460.00000.17790.3553.10952	0.024	0.1959765E	08	0.8226243E	03
57	0.3840460.00000.17910.3488.10952	0.022	0.1959765E	08	0.8226243E	03
58	0.3840460.00000.18030.3429.10952	0.021	0.1959765E	08	0.8226243E	03
59	0.3840460.00000.18130.3374.10952	0.019	0.1959765E	08	0.8226243E	03
60	0.3840460.00000.18240.3323.10952	0.018	0.1959765E	08	0.8226243E	03
61	0.3840460.00000.18330.3276.10952	0.016	0.1959765E	08	0.8226243E	03
62	0.3840460.00000.18420.3232.10952	0.015	0.1959765E	08	0.8226243E	03
63	0.0 0.06210.01091.0000.0	0.0	0.1959765E	08	0.8226243E	03
64	0.0 0.06210.01091.0000.0	0.0	0.1959765E	08	0.8226243E	03
65	0.0 0.06210.01091.0000.0	0.0	0.1959765E	08	0.8226243E	03
66	0.0 0.06210.01091.0000.0	0.0	0.1959765E	08	0.8226243E	03
67	0.0 0.06210.01091.0000.0	0.0	0.1959765E	08	0.8226243E	03
68	0.0 0.06210.01091.0000.0	0.0	0.1959765E	08	0.8226243E	03
69	0.0 0.06210.01091.0000.0	0.0	0.1959765E	08	0.8226243E	03